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Risk assessment for biodiversity conservation planning in Pacific Northwest forests

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Abstract

Risk assessment can provide a robust strategy for landscape-scale planning challenges associated with species conservation and habitat protection in Pacific Northwest forests. We provide an overview of quantitative and probabilistic ecological risk assessment with focus on the application of approaches and influences from the actuarial, financial, and technical engineering fields. Within this context, risk refers to exposure to the chance of loss and typically involves likelihood estimates associated with outcomes. Risk assessment can be used to evaluate threats and uncertainty by providing: (1) an estimation of the likelihood and severity of species, population, or habitat loss or gain, (2) a better understanding of the potential tradeoffs associated with management activities, and (3) tangible socioeconomic integration. Our discussion is focused on threats identified as important influences on forest biodiversity in the region: natural, altered, and new disturbance regimes, and alien and invasive species. We identify and discuss three key challenges and opportunities specific to these threats and quantitative and probabilistic approaches to risk assessment: (1) endpoint selection and calculation of net value change, (2) probability calculations and stochastic spatial processes, and (3) evaluation of multiple interacting threats. Quantitative and probabilistic risk assessment can help bridge the current gap between information provided by general assessment and planning procedures and the more detailed information needs of decision and policy makers. However, management decisions may still fail to win public approval because important risks and issues can be missed or perceived differently by stakeholders. Stakeholder involvement at the inception of a risk assessment can help attenuate these problems. Stakeholder involvement also provides opportunities to communicate information that can influence public risk perceptions and attitudes.
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"Risk is a construct. Before risk there was fate." Bernstein (1996)

1. Introduction

Managing habitat for species of concern and conservation planning implicitly involve the capability to assess and predict the effects of dynamic, stochastic, and interacting natural and human-influenced processes across landscapes. Issues such as timber harvest, fuel build-up, and wildfire hazard now receive the most attention in western U.S. forests, but other disturbances, such as insect and disease outbreaks, changing climate, and alien and/or invasive species (including plants, insects, and diseases) and their interactions also influence forest biodiversity (Wilcove et al., 1998; Logan et al., 2003; Breshears et al., 2005; Dymond et al., 2006). Conserving biodiversity within the context of interacting natural, altered, or new disturbance regimes presents significant management challenges. For example, federal managers in Pacific Northwest forests are charged with protecting old-growth ecosystems in the zone of high wildfire occurence within the eastern range of the Northern Spotted Owl (*Strix occidentalis caurina*), a federally listed species that the Northwest Forest Plan (USDA and USDI, 1994) was designed to protect. Even though the Northwest Forest Plan reduced the overall rate of loss of old-growth forests, the amount of old growth continues to decline in the dry forests regions due to wildfire (Moeur et al., 2005). Ecological restoration and fuel reduction management activities designed to produce open, fire resilient old-growth forests, such as stand thinning and prescribed burning, are often in conflict with habitat conservation goals for Northern Spotted Owls (Spies et al., 2006). Many argue that comprehensive landscape strategies are needed to resolve these types of conflicts and prevent further habitat loss (Wilson and Baker,

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1998; Hessburg et al., 2005; Hummel and Calkin, 2005; Lee and Irwin, 2005; Spies et al., 2006).

Landscape-level strategies to conserve species of concern and their habitats could be advanced by a systematic identification of hazards and assessment of risks, and a clear understanding of potential mitigation outcomes and options. Specifically, risk assessment provides: (1) a process to evaluate threats and uncertainty, including estimations of likelihood and severity of species or habitat loss or gain, (2) a better understanding of potential tradeoffs associated with management activities, including ‘‘no action’’ alternatives, and (3) tangible socio-economic integration. In this paper, we provide an overview of ecological risk assessment relevant to Pacific Northwest forest land managers and others charged with protecting and maintaining species of concern. We focus on threats that have been identified as important to biodiversity conservation in the region: natural, altered, and new disturbance regimes, and alien and invasive species (DeLach, 2006; White and Molina, 2006). Examples of how these threats can potentially affect species of concern and their associated habitats have been extensively covered elsewhere (Wilcove et al., 1998; Stein et al., 2000; Harrod, 2001; Peterson and Robins, 2003; Breshears et al., 2005; Lee and Irwin, 2005; Parks et al., 2005; Dymond et al., 2006; Spies et al., 2006; Odion and Sarr, 2007; Vavra et al., 2007). We propose that quantitative and probabilistic risk assessment can provide a robust and flexible landscape-level strategy for project and planning challenges associated with the conservation of species and habitat protection. This focus is largely relevant to public forest land managers engaged in project and forest planning, but private forest landowners, managers, and other stakeholders interested in forest management certification programs and habitat conservation plans may also find this information useful. Our goal is not to provide an exhaustive literature review, but rather to clarify terminology and highlight issues, opportunities, and challenges within this context. A companion paper in this issue, Ager et al. (2007) provides a specific example of quantitative risk assessment of potential wildfire impacts on Northern Spotted Owl habitat.

2. Risk assessment overview

What is risk and what is a risk assessment? These terms are in common usage, but with a number of different meanings to people. Confusingly, the term *risk assessment* has been loosely used for any document or process that assembles and synthesizes data and information to determine whether or where a range of potential hazards might exist to an ecological system or organism (e.g. environmental impact assessments, bioregional assessments, etc.). The term *hazard* generally refers to anything that has the potential to injure or damage and is synonymous with a term often used in ecological risk assessment: *stressor*. The terms *hazard*, *stressor*, and *threat* are often used synonymously with the term *risk*. However, hazard alone is not risk. For example, does every person who plays a game of football become injured? Risk refers to the ‘‘exposure to the chance of loss’’ (Haynes and Cleaves, 1999), and typically involves likelihood estimates and probable outcomes. The Society for Risk Analysis (2006) defines risk as ‘‘the potential for realization of unwanted, adverse consequences to human life, health, property, or the environment.’’ Although outcomes are traditionally defined as adverse consequences such as property loss, harm, or injury, risk analysis can also include positive effects and net outcomes across both time and space, a point that will be discussed later in more detail.

As human risk assessment became widespread in the 1980s, considerable attention was focused on applying similar formal processes to assess the effects of stressors or threats on ecosystems, creating the discipline of ecological risk assessment (ERA). Over the past 25 years, key definitions, concepts, and systematic processes for ERA have evolved out of statutory frameworks for the regulation of health and environmental risks (U.S. EPA, 1992, 1998; National Research Council, 1983, 1996; Suter, 1993). The EPA defines ERA as ‘‘a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors’’ (U.S. EPA, 1992). Reports that describe the EPA’s process in greater detail are widely available (U.S. EPA, 1992, 1998). Ecological risk assessment is based on the human risk assessment paradigm, but differs in several critical aspects. For example, unlike human risk assessment, in an ERA no single set of ecological values can be generally applied. Ecological risk assessments also frequently assess a range of effects on more than a single species and may include populations, communities, or entire ecosystems. Effects can be extrapolated from one or a few species to entire communities (U.S. EPA, 1992).

The EPA’s ERA framework is the prevailing paradigm in ecological risk assessment (Sikder et al., 2006). However, it is a process, and not a technique. Specific procedures, protocols, and models used within the ERA framework can be qualitative, quantitative, or contain elements of both. Qualitative risk assessments and assessments that contain a combination of quantitative and qualitative components often use expert judgment and ranking systems because data (available data, situation-specific data, relevant empirical information) are lacking or adequate models may not even exist (e.g. Andersen et al., 2004a,b; Landis, 2005; Allen et al., 2006). Yet the complexity of ecological systems can sometimes render verbal models and biological intuition insufficient (Andersen et al., 2004a). Moreover, some risk models have been criticized for using expert judgment about risk and mixing qualitative expert judgment, value-laden terms, and personal preferences (Maguire, 2004). Although lack of data or information may dictate that expert judgment is necessary for risk analysis, there are systematic ways to use expert opinion to avoid mingling opinions about the way the world works with personal values. Systematic use of expert opinion bridges the gap between purely qualitative rating schemes and more quantitative analyses, and can reduce unintentional mingling of facts and values in decision procedures (Shaw, 1999; Maguire, 2004).

Purely quantitative probabilistic tools have been under-utilized in ERA, especially with respect to disturbances. However, probabilistic approaches and influences from the actuarial, financial, and technical engineering fields are increasingly being proposed and applied (Bachmann and Allgöwer, 2001; Brillinger, 2003; Preisler et al., 2004; Finney, 2005; Brillinger et al., 2006; Ager et al., 2007). Adapting tools and techniques from these fields holds great potential for risk assessment and can help bridge the current gap between information provided by general assessment procedures and the more detailed information needs of decision and policy makers. For example, the U.S. General Accounting Office (GAO) found that a systematic assessment of risks was needed to give managers a better understanding of potential tradeoffs associated with fuel reduction treatments. The GAO also noted that neither the National Environmental Policy Act nor National Fire Plan guidance specify how to accomplish this (GAO, 2004). Federal field units in land management agencies currently lack a clear framework and operational tools to quantify how risk might change from proposed fuel treatments.

3. Probabilistic and quantitative approaches to risk assessment: opportunities and challenges

Probabilistic approaches to risk assessment are designed to estimate the expected value of the conditional probability of the event occurring and the consequence of the event given that it has occurred (Society for Risk Analysis, 2006). Complete and perfect knowledge will never be possible, and probabilities, effects, pathways, and outcomes for many processes are often unknown or only partially known. Decisions must nevertheless be made, and are usually made in the context of incomplete knowledge. Risk assessments are conducted when outcomes cannot be predicted, but possible outcomes can be described and likelihoods estimated (Haynes and Cleaves, 1999). Risk can be estimated, but uncertainty still exists across many components of the risk assessment such as sampling, model parameters, human values, etc. The level of uncertainty itself can be evaluated as part of a risk assessment. Uncertainty analyses provide opportunities to discuss knowledge gaps in a transparent way with the public, although governmental agencies and officials may worry that displays of probabilities and uncertainty suggest a lack of understanding (Seife, 2003). For example, most natural disturbance processes are inherently variable and stochastic, and even with perfect data there will be uncertainty related to prediction. Such uncertainty does not infer a lack of understanding, but open discussion of these types of issues may foster effective risk communication (Bradshaw and Borchers, 2000).

In the following sections, we discuss three key challenges and opportunities for quantitative and probabilistic approaches to risk assessment for conservation planning in association with our focus threats: (1) endpoint selection and calculation of net value change, (2) probability calculations for stochastic spatial processes, and (3) evaluation of multiple interacting threats.

3.1. Endpoint selection, values at risk, and calculating net value change

All risk assessments should include a specific and formal description of the *endpoint*. Endpoints are formal expressions of the values to be considered in the risk assessment (Suter, 1993). Endpoints are well specified, measurable, socially and/or biologically relevant (often based on stakeholder input), and sensitive to exposure to the hazard or stressor of interest. The selection of suitable endpoints is also contextual, and will depend on who is evaluating the risk (scientists, land managers, policy makers, the public, etc.) and the overall objectives or purpose of the assessment. Endpoint selection has been a troubling and challenging aspect of ecological risk assessment. For example, typical constructs used in conservation biology such as ecosystem integrity, resiliency, stability, and sustainability are difficult to quantify as endpoints in a risk analysis (Haynes and Cleaves, 1999).

Although the concept of biodiversity is multidimensional and the term has multiple meanings (Olson, 2006), it does not mean that measurable and relevant metrics cannot be specified. Some suggest that all impacts in a risk assessment must be converted into monetary terms (Bachmann and Allgöwer, 2001) and economists have developed methodologies for assigning monetary values to some nonmarket values (Loomis, 2005). When discussing or analyzing monetary endpoints, it is important to note that values are only relevant for a specific time and place. However, other measurable and relevant endpoints (e.g. number of spawning salmon, number of species, or the amount of specific and rare habitats or forest structural stages) can be used in a risk assessment for conservation planning that are not currency based. If a particular organism's specific habitat can be clearly defined, then the amount of habitat can also be a useful endpoint in risk analysis because it is measurable, as well as sensitive to exposure to many threats. That is, the risks to the habitat for specific species or a suite of species can generally be quantified. The amount of habitat for highly visible and/or valued species is also relevant to stakeholders and managers.

Quantitative probabilistic risk analyses use mathematical definitions that describe the relationship between the expected value of the probability of the event occurring at a particular location and intensity, and the *net consequence* or *net value change* given that the event has occurred. Calculating risk or expected loss in this manner is advantageous for risk analysis related to disturbance processes because separate probabilities are quantified for different event intensities and then directly related to net value change. For example, the probability that a high intensity fire will burn a particular forest stand is different than the probability that a low intensity fire will burn the same stand. In addition, the resultant net outcome or net value change (e.g. benefits − losses across both time and space) depends on the threat intensity because values are not uniformly susceptible to the same threats or threat intensities. *Loss functions*, can be used to quantify the relationship between threat intensities and expected net change (loss or gain) across a range of intensities. This approach offers many opportunities to managers because it provides information that can be used to assess risks that are possible and desirable to mitigate, and risks that are not amenable to mitigation or where additional investments in mitigation have no or limited effects. For example, Ager et al. (2007) document that the expected loss of Northern Spotted

Owl habitat was substantially reduced by fuel treatments and the expected habitat loss showed a non-linear reduction with increasing treatment area. Managers and decision makers can use this information to determine where additional investments in fuel treatments will not further reduce wildfire risk.

Ideally, when analyzing net value change, all values of interest would be evaluated using a common metric, although this would be extremely difficult and likely impracticable (assuming it would even be possible to articulate and quantify all values). However, incorporation of net consequences provides an opportunity to evaluate processes that may have beneficial effects depending on the location, frequency, and intensity of the disturbance. For example, wildfires that burn at relatively low intensities and do not threaten property or resources can provide a benefit in the form of fuel reduction and are part of naturally functioning ecological systems (Finney, 2005; Ager et al., 2007). Benefits may also accrue at a later point in time, and thus temporal components are important to consider.

Development of useful endpoints and quantification of ecological and economic damage from invasive species has been particularly problematic because ecological effects and associated damage to relevant values are often difficult to determine. Certainly the establishment and spread of exotic invasive species into new ecosystems can cause irreversible ecological changes and significant economic damage. For example, production losses, control expenses, and other economic damages from the invasion of over 5 million acres of northern Great Plains rangeland by the plant leafy spurge (*Euphorbia esula*) are estimated to exceed US$ 100 million per year (Andersen et al., 2004a). However, purple loosestrife (*Lythrum salicaria*), which has been viewed as a threat to native wetlands vegetation and waterfowl habitat, has actually been found to have few deleterious effects on North American wetlands (Hager and McCoy, 1998). Likewise, Cohn (2005) notes that dramatic claims of water use and native vegetation displacement are either highly questionable or unproven for the invasive riparian tree tamarisk (*Tamarix* spp.).

Quantitative and probabilistic risk assessment requires the assessment of the likelihood and severity of economic or ecological consequences of an exposure to the invasive species. Traditional approaches to risk assessment of invasive species have focused primarily on efforts such as developing classification schemes to predict invasiveness, identifying pathways of introduction (e.g. listing host materials, infested regions, and commodities that may harbor pests), characterizing susceptible resources (e.g. identifying attributes of recipient populations or ecological communities that correlate with vulnerability to invasion), and potential biological consequences of spread (Andersen et al., 2004a). For example, the Plant Protection and Quarantine (PPQ) arm of the Animal and Plant Health Inspection Service (APHIS) is charged with safeguarding agricultural and natural resources from the risks associated with the entry, establishment, or spread of animal and plant pests and noxious weeds to ensure an abundant, high-quality, and varied food supply. APHIS has developed specific and formal science-based risk assessment procedures (http://www.aphis.usda.gov/ppq/pra/). However, the quantification of economic and ecological damage related to the introduction and spread of invasive species remains a key challenge for risk assessment processes related to invasive species (Andersen et al., 2004a).

3.2. Probability calculations for stochastic spatial processes

Disturbances often have spatially explicit features that interact with the landscape, and spatial decision-support tools are helpful to assess and manage these types of threats to biodiversity. A critical issue for risk analysis procedures involving stochastic spatial hazards and their associated probabilities is the development of spatially explicit quantitative analysis. Suter (1993) noted that the spatial aspects of ecological risk assessment were often not addressed, most likely because ERA development was based historically on human health and toxicology, two fields which at the time rarely examined or required spatially explicit models. Another difficulty has been the inability to computatively deal with spatial pattern and process prior to development and increased use of GIS software and advances in disturbance process models. Technological advances in landscape ecology, spatial assessments, and GIS software now facilitate spatially explicit ecological risk assessments.

For many wildland disturbance processes, risk analysis methods entail consideration of initiation, potential for spread (if applicable), and intensity of the processes that are specific to the landscape of interest. For invasive species, environmental heterogeneity, stochasticity, and appropriate dispersal functions are important components of invasion models (Hulme, 2005; Sikder et al., 2006). For example, it is insufficient to predict where an invasive species will spread to in the future without understanding dispersal and colonization of the new environment (Hulme, 2005). The invasiveness of any species is generally highly sensitive to local environmental conditions. When spatial environmental conditions and resource supply differ, opportunities for recruitment and spread differ considerably (O'Neill et al., 1988; Kerns et al., 2006). Yet reaction-diffusion models typically used to quantify invasion dynamics ignore the relationship between the organism and the environment (Sikder et al., 2006).

The development of wildland fire risk provides an excellent example regarding the importance and challenge of calculating probabilities for stochastic spatial processes in risk analysis (Preisler et al., 2004; Finney, 2005; Ager et al., 2007). Bachmann and Allgöwer (2001) note that while some hazards have fixed locations (e.g. power plant, pollutant source), wildland fire can start in any location with combustible fuels. Thus, the analysis of wildland fire risk must account for an infinite number of potential stochastic starting locations. However, under current fire suppression policies, a fire start does not imply spread, since the vast majority of wildfires are quickly extinguished (Finney, 2005). Appropriate methods that deal with spread of the disturbance and associated spatially explicit impact to values can also be included in the risk model.

Using the wildfire example again, this would mean accounting not only for the infinite possibilities of starting locations of the fire, but also accounting for the probability that a fire will reach and impact a particular geographic location and value (Bachmann and Allgöwer, 2001; Finney, 2005). Finney (2005), and Ager et al. (2007) suggest that conditional fire probabilities for risk assessment can be characterized by estimating the probability of burning with a given fire behavior for all areas within the area of interest using random ignitions and spatial fire simulations that account for effects of spatially varying fuels, topography, and weather.

3.3. Multiple interacting threats

Developing probabilistic risk models for stochastic processes is challenging, but the task is even more daunting when synergistic effects among disturbances are included (Preisler et al., 2006). Yet disturbance synergism and multiple perturbations and resulting outcomes or ecological surprises (*sensu* Paine et al., 1998) are widely recognized. For example, wildfire and insect infestations are two major disturbances of forest lands in the U.S., and synergistic associations are frequently described and assumed between them. Trees weakened by fire can be more susceptible to attack by insects such as bark beetles (*Dentroctonus* spp.) and tree damage and mortality from fire can create ‘‘focus’’ trees, which can potentially attract additional insects (McCullough et al., 1998; Schwilk et al., 2006). McHugh et al. (2003) and Cunningham et al. (2005) followed tree mortality for 3 years after wildfire and found that bark beetles were more likely to attack trees injured by fire; however, others have found that beetles did not preferentially attack trees with fire injured boles, but attack success was higher in injured trees when beetle population levels were low (Elkin and Reid, 2004). Bark beetle populations do not always respond to stand treatments and stand replacement wildfires (Sanches-Martinez and Wagner, 2002).

Another widely documented synergistic process is the spread of invasive plant species into disturbed areas and subsequent changes in ecosystem processes. For example, both prescribed and natural wildfires can introduce or spread exotic invasive species (D'Antonio, 2000), particularly in association with either widespread or localized high severity burn conditions (Crawford et al., 2001; Keeley et al., 2003; Korb et al., 2004; Kerns et al., 2006). The invasion of some exotic species can also alter future disturbance processes such as fire. Cheatgrass (*Bromus tectorum*) invasion is a salient example. Cheatgrass is widely distributed in North America (USDA and NRCS, 2004), is abundant and dominant in western steppe communities (Mack, 1989), and has invaded and become dominant in several locations throughout eastern Oregon and Washington (Quigley and Arbelbide, 1997). This annual grass forms dense, continuous stands that mature early in the season, resulting in increased rates of fire spread, intensity, and fire frequency compared to native species (Menakis et al., 2003; Zouhar, 2003).

These examples of disturbance synergies illustrate the geometric complexity of risk assessment when multiple stressors are considered. The importance of considering multiple stressors is widely recognized and described in the literature, but development of risk analysis tools to deal with these synergies is in its infancy and few examples exist. Landis (2005) noted that the EPA ERA framework was originally designed for single stressors and endpoints, and the incorporation of multiple stressors within this framework has limitations. For example, it is intractable to attempt to combine measurements taken with distinctly different units, although qualitative ranking can be used to overcome this difficultly (Landis, 2005). However, quantitative assessment of multiple interacting threats is an area of active research and statistical tools such as spatiotemporal logistical regression (Brillinger, 2003; Preisler et al., 2004, 2005; Brillinger et al., 2006; Preisler et al., 2006) and simulation modeling (Finney, 2005; Ager et al., 2007) are potentially promising approaches that avoid the use of qualitative ranking systems.

4. Conclusions

Quantitative and probabilistic risk assessment can provide a robust and flexible landscape-level strategy for project and planning challenges associated with the conservation of species and habitat protection. We adopt Society for Risk Analysis (2006) definitions that: (1) risk is the potential for realization of unwanted, adverse consequences to human life, health, property, or the environment; and (2) the estimation of risk is based on the expected value of the conditional probability of an event occurring times the consequence of the event given that it has occurred. Well-specified, measurable, socially and/or biologically relevant (based on stakeholder input) values at risk that are sensitive to exposure to the hazard or stressor of interest are critical. Quantitative probabilistic risk analyses use mathematical definitions that describe the relationship between the expected value of the probability of the event occurring at a particular location and intensity, and the net value change given that the event has occurred. Both positive and negative benefits and losses can also be included and assessed across space and time. A critical issue is the development of appropriate loss functions across a range of threat intensities, and the quantification of spatially and temporally explicit patterns of highly stochastic hazards. The application of formal risk analysis to conservation problems offers many opportunities to managers because the approach exposes risks that are possible and desirable to mitigate, and risks that are either not amenable to mitigation, or not cost effective. We found that although the interacting effects of multiple stressors are widely recognized and described in the literature, development of risk analysis tools to deal with these synergies is in its infancy and few examples exist. However, this is an area of active research, and several frameworks are being developed.

Although quantitative probabilistic risk analysis hold great promise in the context of conservation planning for species of concern, public support of management decisions may still fail to win approval because important risks and issues can be missed or perceived differently by stakeholders (National Research Council, 1996; Haynes and Cleaves, 1999). This issue is particularly relevant for public land management and biodiversity, as stakeholders hold a wide variety of views regarding biodiversity, values, conservation of rare species, and associated hazards (White and Molina, 2006). Public perceptions of risk are complex and context driven, and representing risk as an expected loss estimate to the public is over-simplistic (DEFRA, 2000). Whether a risk is acceptable or not depends on both broad societal issues and scientific assessments. The National Research Council (1996) has suggested that risk assessors expand risk characterization using an analytical-deliberative approach that involves stakeholders from the very inception of a risk assessment. Evaluating social risk perceptions in this way can also help communicate information about the risk to the public, which may alter certain risk perceptions and risk attitudes.

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